Waterwheels...Part 2...

Design calculations for no-head, low-head waterwheels

(This is the second of our three-part series on waterwheels. The third installation (Issue No. 18) will deal with overshot wheels.—Editor.)

By Rudy Behrens

For those of you who are still awake after reading my first installment, I will now continue. This part will deal with the design factors you will need to know to build a low-head waterwheel. It's somewhat technical, but it is essential to know if you are to build a successful no-head or low-head waterwheel.

Head, spouting velocity

The most important thing to determine is **head**, or how far the water falls. If you have a small dam or waterfall the answer is the difference in height between the free water surface on the **upstream** side, and the free water surface on the **downstream** side, in inches or feet. If you have a swift moving stream, the answer is only a bit harder to figure out.

The answer is in the equation for spouting velocity, which is the equation that describes the speed of any falling mass: **velocity squared divided by two times a gravitational constant**, which is expressed mathematically as $V^2/2G$. The gravitational constant (G) is 32.2.

You can measure the velocity of a stream by running two strings across it, some measured distance apart. You then throw in corks, or pingpong balls and time their travel between the strings, in feet-per-second. Do this several times at several points along the stream and calculate an average velocity. Once this is done, you take this figure and multiply it times itself, then divide that number by 64.4, which is two times the gravitational constant. This will convert your velocity into a **head**.

Diameter of wheel

When designing an undershot wheel, you must know the **head** since the optimum diameter of the wheel is three to six times the head. Let's say you measure your stream and get an average velocity of 10 feet-per-second. That number times itself is 100. Divided by 64.4, we get an answer of 1.55 feet. In other words, the water is moving as fast as it would if it had fallen 1.55 feet. Your wheel should then be at least 4.65 feet to 9.3 feet in diameter (E.g.: 3 x 1.55 = 4.65 or 6 x 1.55 = 9.3).

Whenever possible, make the wheel as large as you can. However, there would be no improvement in performance if it were larger than 9.3 feet.

The next step is to compute the working diameter. This is the overall diameter minus the head. Now, multiple this number times PI (which is the mathematical constant equal to approximately 22/7 or 3.14) to get the working circumference. The answer will also be in feet.

Blade spacing

When you install the wheel, you will **submerge the blades a distance equal to the head**. Therefore, the spacing between the blades should be some convenient number times PI to get the working circumference. The answer will also be in feet.

In our example I have decided to work with the 9.3 foot diameter from the figures above, so the working circumference is 24.35 feet (9.3 minus a head of 1.55 = 7.75 feet. 7.75 x PI 24.35 feet.)

The space between the blades should be less than 1.55 feet, which in our example is the head. Let's use 1.5 feet, so the number of blades is 16.23 (24.35/1.5 = 16.23) or rounded to 16. So, we will build a wheel 9.3 feet in diameter with 16 blades.

Making it efficient

But how fast will it turn? The most efficient energy transfer occurs when the wheel speed is between 67% and 90% of the water speed. For undershot wheels, I usually go for the lower figure to allow for slow days. Sixty seven percent of 10 feet per second is 6.7 feet per second, which is the same as 402 (6.7 x 60 = 402) feet per minute. You divide this by the working circumference of 24.35 feet per revolution. This gives you an answer of 16.5 (402/24.35 = 16.5) revolutions per minute. That is your best rotative speed.

As you can see, it is rather slow. That is why you will need a speed increasing system, as we said in the last issue.

Actual power of wheel

The power you will get depends on the width. For our example, I have chosen three feet. The working cross section will then be width times submergence. In this case 1.55 feet times 3 feet, or 4.65 square feet. Multiply this times our velocity of 10 feet per second and we get a design flow of 46.5 cubic feet per second. Power is equal to **flow** times **head** divided by 11.8. Therefore, we have a **flow** of 46.5 cfs **times** a **head** of 1.55′ divided by 11.8. 46.5 x 1.55 = 72.075. 72.075/11.8 = 6.1 kilowatts or kw/.746 = horsepower. 8.2 horsepower. We should assume an efficiency of 70%. So, our hypothetical wheel will produce 5.7 horsepower or 4.3 kilowatts.

These calculations apply to **any** low-head waterwheel. The only thing that changes among the various designs is the speed or efficiency. If we were to make our example as a poncelot wheel, all the design parameters would be the same. The blades would not be straight. Instead, they would be offset from the radius of the wheel by a negative 30 degrees and the lower portion would be curved to 60 degrees of arc in a radius equal to the head. This change will raise efficiency to the 80 + % range.

Wheel should be steel

Materials should always be a good grade of steel. A steel grade of A36 or B36 works very well. Twenty gauge or thicker is good. We always use 1/8" at FITX Waterwheel Company, and ours have withstood direct hits by ice flows of more than a ton. If you use corten, a weathering steel, it will not need painting and it will acquire a reddish color that resembles wood. Staticly balance the wheel before installation.

No matter how tempting, never use wood. It rots and holds water unevenly. This unbalances the wheel and makes it unsuitable for any use except grinding grain. Be very accurate in all you measurements, especially those concerning flow and head. If they are wrong, everything is wrong.

Use wood bearings

I recommend oil-impregnated wood bearings. They can be obtained from the POBCO Bearing Company of Worcester, NILA. Waterwheels turn too slowly for ball or sleeve bearings; they cannot maintain a uniform lubricant field. This tends to ruin the bearing quickly. The wood bearings have a "wick" action that maintains uniform lubricant.

Next issue, we will adapt these equations to overshot wheels and get into the economics of going into the cogeneration business.

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A FITZ Waterwheel Company all-welded steel undershot wheel.